RIPARIAN VEGETATION OF THE SAN JOAQUIN RIVER

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Department of Water Resources
San Joaquin District
Environmental Services Section
Fresno, California

for

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RIPARIAN VEGETATION OF THE SAN JOAQUIN RIVER

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by

G.W. Moise
Beth Hendrickson
Environmental Scientists

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This TIR is primarily a working paper and is subject to revision or replacement. Its primary use will be as a source of information for management of the San Joaquin River.

EXECUTIVE SUMMARY

During the spring, summer and fall of 2000, Environmental Services Section staff from the State of California Department of Water Resources' San Joaquin District studied the riparian corridor vegetation of the San Joaquin River from Friant Dam to the confluence with the Merced River. This study spanned five hydrologic reaches and nearly 150 river miles: Reach 1 (Friant Dam to Gravelly Ford: RM 267 to 229), Reach 2 (Gravelly Ford to Mendota Pool: RM 229 to RM 205), Reach 3 (Mendota Pool to Sack Dam: RM 205 to RM 182), Reach 4 (Sack Dam to Bear Creek: RM 182 to RM 136), and Reach 5 (Bear Creek to the confluence with the Merced River: RM 136 to RM 118).

The Bureau of Reclamation (Bureau), San Joaquin River Riparian Habitat Restoration Program, commissioned this study to expand on the 1998 report, *Historical Riparian Habitat Conditions of the San Joaquin River* (Jones and Stokes, 1998). The Jones and Stokes report documents and quantifies broad changes in habitats, soils and land use of the Friant Dam-to-Merced River riparian corridor from the early part of the 20th century to the late 1990's. The present study is a more detailed and in-depth characterization of the vegetation. To our knowledge, no work on the riparian vegetation of the main stem of the San Joaquin River has ever been done in such detail. This baseline vegetation mapping ideally could be combined with soils maps, land-use considerations, and hydrologic and ground-water data (from the U.S. Army Corps of Engineer's Comprehensive Study on the San Joaquin River), with the goal of creating a map of areas with restoration potential. The current study would then become one indispensable facet of a larger feasibility study concerning the restoration of some of the biological and ecological heritage of the San Joaquin River, within the constraints of the current hydrologic regime and the infrastructure of levees, dams canals and other structures and conveyances. The immediate focus of this study is to identify, describe and map the extent and diversity of riparian habitats found along the main stem of the San Joaquin River, to document the diversity and distribution of plant species, both native and introduced, to locate and map invasive exotic vegetation, and to provide necessary information toward the development of a map of restoration potential along the river.

Vegetation maps were created as ArcView polygon themes based on georectified aerial photos, delineated at a scale of 1:4000. The minimum mapping unit for vegetation types was 0.3 acres, although wetlands and some exotic plant polygons were as small as 0.1 acres. Field verification was intensive, with 42% of the vegetated polygons checked, representing a third (29.7%) of the acreage of native and naturalized vegetation in the study area.

Vegetation was classified using a modified Holland system (Holland, 1986). Eleven basic vegetation communities were found along the San Joaquin. These include cottonwood riparian forest, herbaceous (=grassland), mixed riparian forest, willow riparian forest, riparian oak forest, riparian scrub, river wash, wetland, willow scrub, exotic tree (usually *Eucalyptus* or tree of heaven [*Ailanthus altissima*]) and Arundo (*Arundo donax* or giant reed). Woody vegetation types were additionally assigned a structural/size classification from one to six, based on the work of Hink and Ohmart (1984). This added component of classification, which uses canopy height and understory density, yielded 30 vegetation/structural types altogether for our study area.

In addition to the data about exotic trees and *Arundo* in the vegetation layer, the Bureau needed more detailed information with respect to the extent and type of invasive exotics found along the river. Many of these invasive species occur in small clumps or as individuals, not detectable on the aerials or mappable on the scale of the vegetation theme. Their locations were noted in the field and later mapped on a separate GIS layer.

With the aid of a crew of students and scientific aides, 125 transects (average length = 102.4 meters) were used to study in detail the vegetation occurring in each of the five hydrologic reaches. End points of each transect were located with a GPS unit. Habitat photos were taken from the endpoints of each transect. Along each transect we measured canopy coverage by species, and diameter at breast height of all stems (>5 cm in diameter) found within 3 meters of the transect centerline. Cover data for herbaceous species was estimated using 0.25-m-square plots, placed every 5 meters along the transect centerline. The presence of noxious and invasive weedy species was noted and added to the polygon map.

GIS layers were constructed in ArcView 3.2. These include:

1) Vegetation/land use
2) Weedy invasives
3) River mile (from USACOE)
4) Transect end points and transect lines
5) Corridor width (distance between confining levees or bluffs)
6) Georectified aerial photography (from USACOE)

The data tables associated with the vegetation/land use themes include polygon acreage and perimeter, type of vegetation, field-verification status, comments, other species noted, and Hink and Ohmart structural class for the woody vegetation types. The transect themes include a "hot-link" to the habitat photos taken at each transect end point, and a link to the field data recorded along each transect.

Overall, we encountered 256 species in 61 plant families, of which 129 were native. These include 18 canopy tree species, 4 vines, 2 shrub species and 232 herbaceous species. The highest overall species diversity is found in Reach 1, while Reaches 4 and 5 had the highest percent of native herbaceous cover. Mixed riparian forest and willow riparian forest had the highest diversity of species, both native and overall. Native trees compose 95.6% of canopy cover.

Of 59,941 acres of riparian corridor and floodplain mapped, about half is native or naturalized vegetation, the remainder being urban, disturbed, cultivated, or open water. Overall cover of woody vegetation (forests, woodlands, and scrubs) is approximately 25% of the total natural vegetation mapped. Of this, a mere 3,809 acres is actually riparian forest. The majority of the remaining acreage is covered by herbaceous vegetation.

Weedy invasives included many species, the most abundant of which were eucalyptus and giant reed. At present, scarlet wisteria is found only in Reach 1, but this seriously invasive plant is displacing even willow scrub in that reach. Attempts to eradicate this plant along the San Joaquin River below Friant Dam have been only partially successful. It will require close observation to keep it in check in the coming years. Tamarisk is not yet a major

problem in the study area, although it is in many sub-drainages of the southern San Joaquin Valley.

No correlation was found between river mile and overall plant diversity, between river mile and native plant species diversity, or between levee confinement width and native cover or native plant species diversity. A negative correlation was found between river mile and total native cover ($r = -0.81$).

Factors important in evaluating the restoration potential of any given portion of the river include: presence/extent of exotic invasive species, proportion of native riparian species, adjacent land use, ground water, and the seasonal cycle of river stages. Manipulating flow regimes during critical seasons can potentially augment natural recruitment and survival of riparian tree species, particularly willows and cottonwoods. Restoration of riparian vegetation is likely to be most successful in those portions of the river that contain high proportions of natives (as seed/propagule sources), where exotic weeds can be kept under control, and in which flows may be manipulated to encourage riparian tree species recruitment. In addition, if efforts supported by federal and state agencies are combined with community-based focus on areas near urban centers with aesthetic and recreation potential, the likelihood of long-term success will be enormously enhanced.

Reach 1, adjacent to the Fresno metropolitan area, offers such a scenario. The San Joaquin River Parkway has already expressed an interest in such activities, and preliminary design work has targeted the Milburn area of north Fresno for channel and floodplain modifications. Combining weed control efforts throughout Reach 1 of the San Joaquin River (currently under consideration by the Bureau) with said re-engineering and subsequent revegetation would go far towards restoration of aesthetic and functional values to this section of the river.

A pilot flow study in Reach 2 (Jones and Stokes, 2000) is investigating the effect of increased flows during May to September on the establishment of riparian tree species, particularly willows and cottonwoods. The results of this study, although preliminary, indicate differential responses of cottonwoods versus Goodding's willows (*Salix gooddingii*) to the timing of flows, and that scouring flows are critical to create bare areas for recruitment for these species. Continuance of this study and others in the San Joaquin basin (cf. Stillwater Sciences, 2001) will be instrumental in understanding recruitment of riparian vegetation, and in establishing methods for large-scale restoration using modifications to the flow regime. Enhancement of riparian vegetation in Reach 2 may well be the end result.

Reaches 4 and 5 are largely within and/or adjacent to the various units of the San Luis National Wildlife Refuge complex. These large areas of public lands contain by far the greatest extent of floodplain vegetation in our study area. Restoration potential would be high for any additional acreage along the San Joaquin River if they were to be acquired as part of public or private conservation efforts. The proportion of native vegetation cover is greater than upstream (possibly because of the relatively high water table in these reaches as well as adaptations of native plants to the salinity/alkalinity of the soils and river water). Thus, seeds and propagules are in close proximity to potential restoration sites. Weedy species are also not as abundant as in other areas.

Future studies recommended include:

1) revisit transect locations in five years time to retake habitat photos and to document changes along some or all of the transects

2) encourage university/agency research to gain a better appreciation of mechanisms responsible (i.e., salinity/ alkalinity, water table) for the increase of native cover in the downstream reaches

3) continue study of recruitment and size class distribution of riparian trees

4) inventory/analysis of coarse woody debris

5) census invertebrates that use this and other substrates in the riparian corridor

6) examine DFG's Wildlife Habitat Relations system as applied to the San Joaquin River

7) document avian usage of the riparian corridor

8) digitize the 1917 USACOE maps of the San Joaquin River and comparing modern and historical channel migration/sandbar configuration

9) initiate eradication of exotic invasive species

In conclusion, baseline studies detailed herein will be useful, even critical, to restoration and conservation considerations in the San Joaquin River basin. Information obtained as a result of these and subsequent studies can enhance our understanding of riparian processes in the San Joaquin hydrologic basin. It is hoped that in combination with ground water and river stage data, this study will lead to focused restoration efforts, particularly when subsequent to channel/floodplain modifications, enhanced flows and conservation easements or acquisitions.

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INTRODUCTION

In 1999 the U.S. Bureau of Reclamation approached the California Department of Water Resources (DWR) to commission a detailed study of the riparian vegetation of the San Joaquin River. An earlier study had outlined the historical habitat conditions from the confluence of the San Joaquin River with the Merced River to Friant Dam near Fresno (Jones and Stokes, 1998). The Jones and Stokes study documented broad changes in the riparian vegetation and adjacent land uses from the early part of the twentieth century to the mid 1990's, using early mapping by the U.S. Army Corps of Engineers (ACOE), and aerial photography from the 1930's to the 1990's, but included only cursory field-verification. More detailed study was needed to assess the current state of the riparian ecosystem and provide information about potential for restoration. The study described in the following pages is, to our knowledge, the first in-depth, comprehensive characterization and assessment of riparian vegetation on the San Joaquin River. The major components of this project include vegetation mapping with extensive field verification, and habitat transects sampling all vegetation types of the riparian corridor in all study reaches.

This study, ideally combined with soils maps, ecological, hydrological, and ground-water data from other State and federal studies (notably the ACOE *Sacramento and San Joaquin River Basins Comprehensive Study*, the *Pilot Flow* studies commissioned by the Bureau and Friant Water User's Authority, and Stillwater Science's *Mechanistic Approach to Riparian*

Restoration in the San Joaquin Basin), will be instrumental in the development of effective management options for the San Joaquin River. The present study establishes baseline data from which the efficacy of restoration efforts may be assessed, or indeed from which any changes in riparian habitats may be determined, whether due to hydrological, climatic, or land-use considerations. The level of detail is such (0.3 acre) that changes may be easily determined from aerial photographs and/or on-the-ground inspection. In addition, GPS-located transects and habitat photos taken from the end points of each transect allow for detailed tracking of changes in species composition or habitat type along the transect lines within the study area. All of the data, including aerial photos, mapped habitat patches, weedy exotic species, transect locations, river mile markers, habitat photos, and individual transect data, has been compiled into an ArcView 3.2 database, and that is available on a companion CD. Eventually, it is hoped that these data will be combined with ground water and hydrologic data in the form of GIS layers to develop a map of restoration potential along the main stem of the San Joaquin River.

METHODS

Natural vegetation together with general land-use adjacent to and within the San Joaquin River corridor was mapped from Friant Dam to the confluence with the Merced River. A goal of the mapping project was to gain information about potential restoration sites as well as to establish baseline information about vegetation in the river area. Thus, general land use information was relevant to the study goals, as was information about the presence and abundance of invasive exotic plant species that could impact restoration of native habitats.

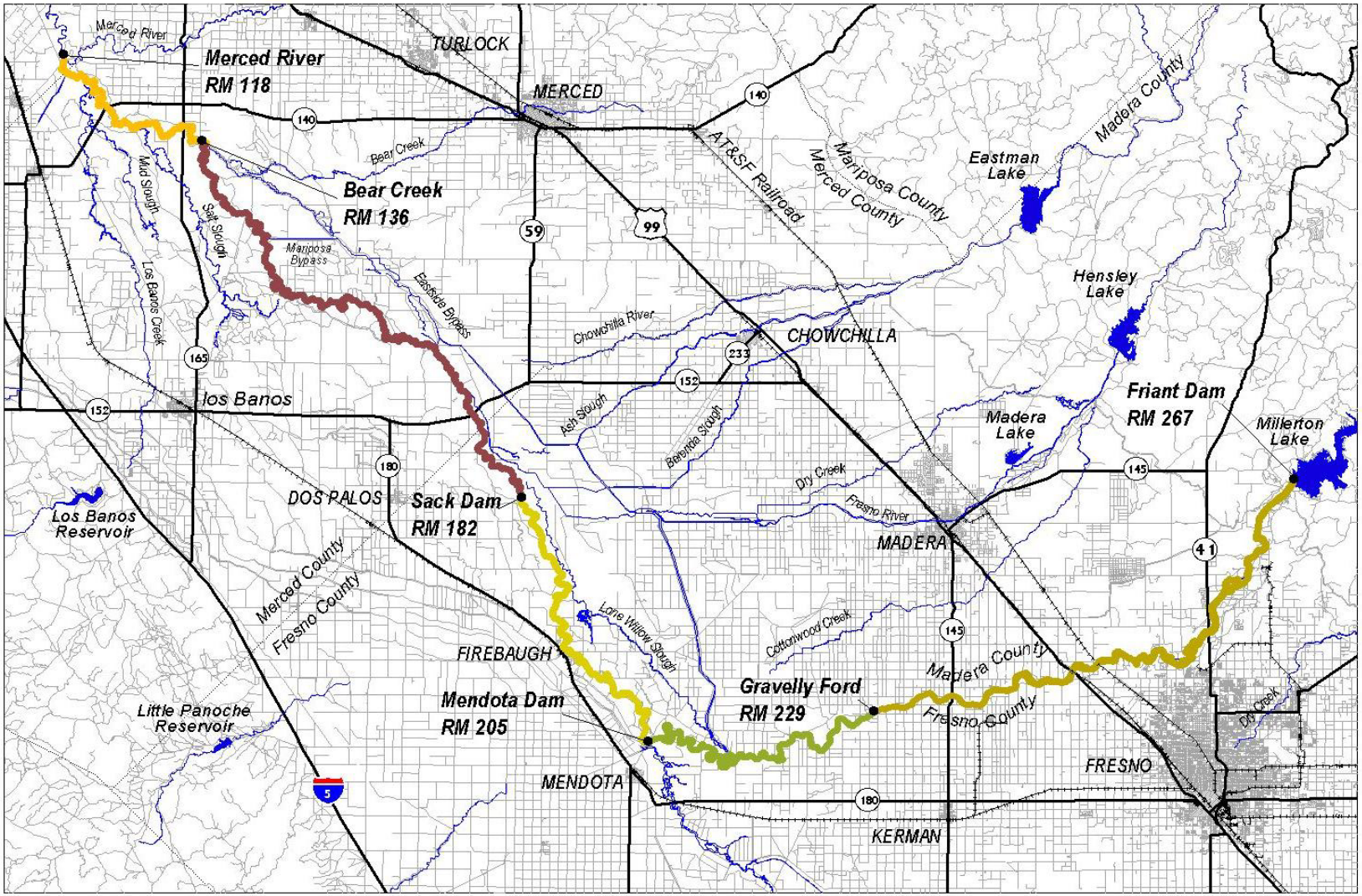
Previous reports (JSA 1999) defined five hydrologically distinct reaches along the149 miles of the main stem of the San Joaquin River between its confluence with the Merced river and Friant Dam (See map, following page):

Reach 1--(Friant Dam to Gravelly Ford: RM 267 to 229)
Reach 2--(Gravelly Ford to Mendota Pool: RM 229 to RM 205)
Reach 3--(Mendota Pool to Sack Dam: RM 205 to RM 182)
Reach 4--(Sack Dam to Bear Creek: RM 182 to RM 136)
Reach 5--(Bear Creek to the confluence with the Merced River: RM 136 to RM 118)

This convention was followed in the study described below, and vegetation data from each reach was analyzed and compared with the other reaches. Additionally, Reaches 1 and 4 were further divided into two sub-reaches, “a” and “b”, for purposes of some of the analysis.

Data Sources

High-resolution black and white aerial photos of the river area downstream from Gravelly Ford were taken in July 1998 and color aerial photos were taken between Gravelly Ford and Friant Dam. Aerial photos were converted to digital format and georectified for use with GIS. The photos were taken following the flood year of 1997. The year 1998 was also unusually wet; wetlands and open water habitats mapped during this project may consequently be more extensive than in normal years. Some areas were scoured during



San Joaquin River
Vegetation Mapping Study Reaches

Environmental Services Section/San Joaquin District, November 2001

the 1997 floods, and subsequent, successional events have resulted in vegetative cover on areas that appear scoured in the photos. Other changes that occurred between the time the photos were taken and the time of the mapping included some clearing of some riparian vegetation for mining and other activities, and minor channel and sandbar migration. Overall, though, field verification revealed that there have been few changes to the vegetation since the time the photos were taken.

Mapping Methods

Vegetation and land-use polygons were mapped as a GIS layer using ArcView 3.2. Mapping boundaries generally followed those used by Jones and Stokes (1999). The map boundary is 1000 feet outside the levee or, where there is no levee, 1000 feet outside the outer edge of the riparian vegetation. In areas where riparian vegetation extends out into adjacent sloughs or side channels, and natural vegetation is present throughout, the entire area covered by the aerials was mapped. Maps were drawn at a scale of 1:4000, with a minimum polygon size of 0.3 acre. Units of vegetation smaller than 0.3 acres were included within associated larger units. Occasionally, polygons smaller than 0.3 acres were delineated for particular vegetation types of interest, e.g. wetlands and invasive exotics. Vegetation types were distinguished by means of their signature on the aerial photographs and by comparison with other, known polygons in the same area. Areas with no naturally occurring vegetation were distinguished as agricultural fields, open water, disturbed areas, or urban areas.

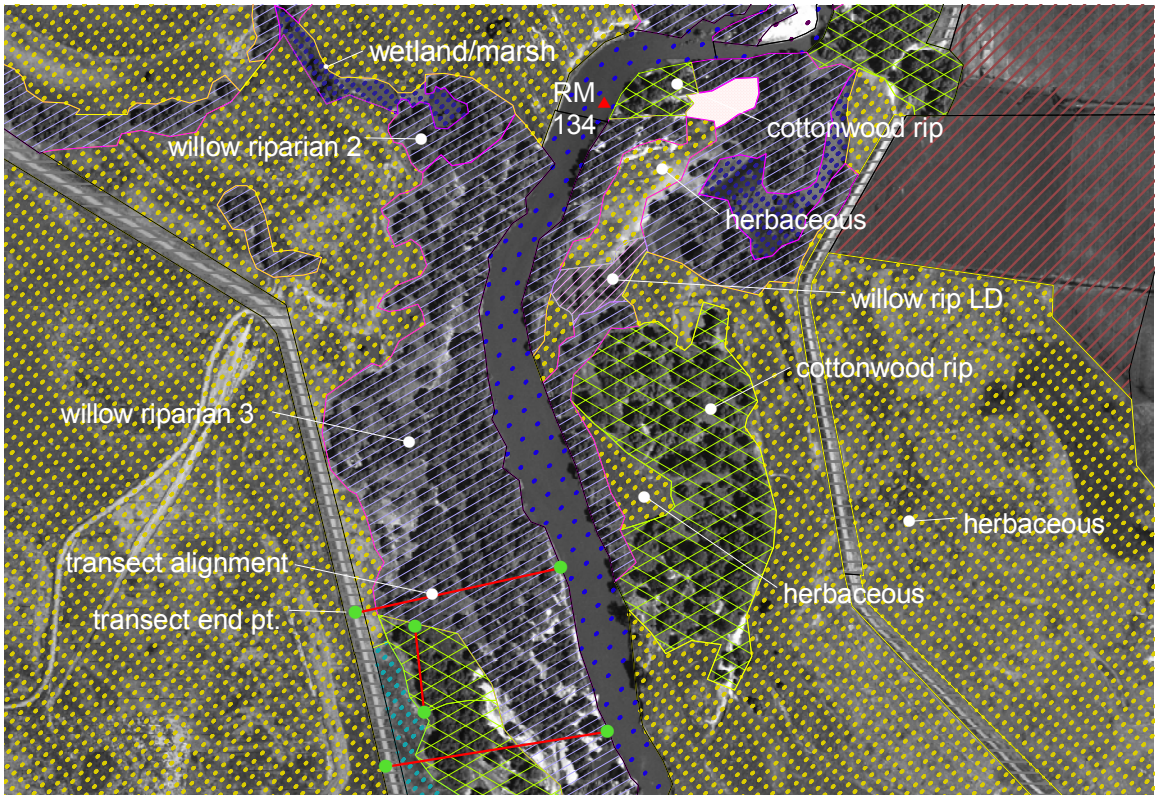


Fig 1. Representative GIS vegetation layers over georectified aerial photograph-RM 134.

Woody vegetation units abutting herbaceous units were extended to include a "zone of influence" of one-half a canopy width extending into the herbaceous cover. Small gaps

(less than two canopy widths) within otherwise continuous woody canopy cover were ignored. In the case of low-density woody vegetation, canopy cover could not exceed 50 percent. Generally, individuals located outside a stand were excluded if the gap exceeded two canopy widths. Evidence of continuous habitat conditions, such as swales, riverbanks, etc. were considered in evaluating whether to include scattered individual trees or groups of trees within a single polygon.

Woody vegetation types were also given a structural classification; this is the Hink and Ohmart (1984) class (Table 1). Hink and Ohmart classes from 1 through 6 were noted in the field; the structural class of those polygons not field verified was inferred from aerial signatures and comparison with other, known polygons from the same area.

Table 1 Hink and Ohmart Structural Classification

This is the single digit following the vegetation acronym, (e.g. MW 4)
1--Canopy 40 feet or greater in height, dense understory
2--Canopy 40 feet or greater in height, sparse understory
3--Canopy 15-40 feet, dense understory
4--Canopy 15-40 feet, sparse understory
5--Canopy less than 15 feet, dense understory
6--Canopy less than 15 feet, sparse understory

In addition to the vegetation map, a second GIS theme was generated showing locations of invasive exotic species. These included giant reed (*Arundo donax*), eucalyptus (*Eucalyptus* spp.), and scarlet wisteria (*Sesbania punicea*) among others. Locations of these invasive species were noted during field surveys, since, with the exceptions of eucalyptus and large patches of giant reed, the exotic species are usually not evident on the aerial photos.

Field Verification

Field verification of the vegetation maps was done over the summer and early fall of 2000. Verification was done from a canoe or from a vehicle, depending on property access. About 14.5 miles of river were not accessible for field verification; this is the stretch from rm. 155.5 to 170, just south of the San Joaquin National Wildlife Area. In all, about 35 percent of all mapped polygons were field checked, representing about 16 percent of the mapped acreage. If agricultural fields, open water, urban and disturbed areas are taken out of the dataset (leaving just those polygons with native or naturalized vegetation), then 42 percent of vegetated polygons were verified, representing 30 percent of the acres of natural vegetation mapped.

In areas where field surveys revealed vegetation different from that appearing on the aerials (due to human disturbance, successional changes, or channel migration), the map was amended to reflect the current situation. Such changes are noted on the comments field of the database file that accompanies the ArcView layer. Species composition or

unusual species were sometimes noted in the field; these comments were included on the "other species" field of the database.

Vegetation and Land Use Classifications

The vegetation and land-use categories mapped are described below, together with an explanation of how these units were identified. More complete descriptions of the native vegetation types and their ecology are given in the Results section.

AG = Agricultural field. This includes all areas where there was visual evidence of recent plowing, irrigation etc. No distinction was made between types of crops. Farm roads were generally not separately delineated, since they can be moved or removed depending on the owner's requirements.

AR = *Arundo donax*. This invasive weed, called giant reed, was mapped where it occurred in large stands visible at the mapping scale of 1:4000. Such stands have a distinctive visual signature on the aerials. Giant reed reproduces clonally and outcompetes the native vegetation, creating large stands that have no diversity and provide poor wildlife habitat values.

CW, CWLD = Cottonwood riparian and cottonwood riparian, low-density. This corresponds to Holland's Great Valley Cottonwood Riparian Forest.

D = Disturbed. This designation was used for areas where it is unlikely or impossible to find significant native vegetation; it includes roads, canals, levees, structures and associated landscaping, parks, golf courses, and active gravel mines. It does not include urban areas (see below). Roads were mapped where they appeared to be permanent or at least two lanes in width; farm roads were generally included in the AG polygons and not mapped separately.

EB = Elderberry savanna. Although there are only a few polygons of this vegetation type within the study area, it is a significant resource due to its scarcity (it was thought by some to have been extirpated from the San Joaquin Valley) and the fact that it provides potential habitat for the endangered valley elderberry longhorn beetle.

EXO = Exotic tree. This vegetation type mostly consisted of eucalyptus stands; also included are a few stands of tamarisk and tree-of-heaven. Species were noted in the database table for the layer.

H = Herbaceous. Initially a distinction was made between grassland and herbaceous riparian vegetation, but in practice the two types overlapped so much it was not practical to separate them, so they were combined into the functional category of herbaceous vegetation. "Grassland" in the study area mostly consisted of annual exotic herbs and grasses; herbaceous riparian areas were similar in composition but generally less dense due to the poorer soils on scoured areas near the river channel.

MR, MRLD = Mixed riparian and mixed riparian, low-density. This corresponds to the Holland classification of Great Valley Mixed Riparian Forest.

OAK = Riparian oak. This classification combines Holland's Great Valley Valley Oak Riparian Forest and Valley Oak Woodland, ranging from closed canopy stands to open savannah, all dominated by *Quercus lobata*.

RS = Riparian scrub. This classification does not correspond to any of the riparian scrubs in the Holland system, but was commonly observed, especially in channelized portions of the river It consists of a mix of semi-shrubby perennials and woody vines, usually strongly dominated by one of three species: *Rosa californica*, *Artemisia douglasiana*, or *Rubus discolor*. Possibly this association would be succeeded by one of the woody riparian communities in the absence of disturbance.

RW = Riverwash. These areas are scoured banks and bars within or adjacent to the active river channel, without significant vegetative cover. Some areas that appear as riverwash on the photos were found during field surveys to support open to dense stands of willow scrub; these were mapped as willow scrub and so noted in the "Comments" field.

URB = Urban. This includes urban areas and suburban housing developments, but not single houses surrounded by fields; these would fall into the "disturbed" category above.

WA = Open water. This does not include water in canals or irrigation ditches; these were included in the disturbed category or as part of the AG polygons. In some cases, open water habitat grades into emergent marsh; boundaries between the two were set at the edge of the vegetation as it appears in the photos or as noted in the field.

WET = Wetland/marsh. All types of wetlands and emergent marsh vegetation fall into this category. Wetlands were identified visually by vegetation changes, by topographical features, and by proximity to water bodies. Seasonal wetlands were included where these were visually apparent; however there may be seasonal wetlands present that were not mapped due to the difficulty of distinguishing them in grassland habitats. Also, as noted above, the photos used for interpretation were taken in an unusually wet year; some areas mapped as open water may contain seasonal wetlands or even upland vegetation in normal years.

WR, WRLD = Willow riparian and willow riparian, low-density. This vegetation type is a subtype of Holland's Great Valley Cottonwood Riparian Forest. Willows, principally *Salix gooddingii*, dominate this habitat type, in which cottonwoods are only a minor component, if present at all along the downstream reaches of the river.

WS, WSLD = Willow scrub and willow scrub, low-density. This is equivalent to Holland's Great Valley Willow Scrub.

TRANSECTS

Transect locations were pre-selected from the aerial photographs to sample the range of vegetation types found along the river in a given reach. Transects (n = 102) perpendicular to the course of the river channel were established between the confining levee or river terrace slope and the water's edge. Additional or "auxiliary" transects (n = 23) were also used to amplify sampling of rare or uncommonly encountered habitat types. Auxilliary transects were generally oriented parallel to the river's course to accommodate the usual orientation of habitat patches. Each habitat polygon crossed by a transect was given an individual identifying number on the data sheet. The width of the river channel adjacent to, or crossed by a transect was determined by optical range finder or by direct measurement with cloth tape. Transect end-points were located to +/- 5 –meters using Garmin 12 GPS units.

Woody Riparian Species: Within each habitat type encountered along the transect tape, data was recorded for canopy cover, sub-canopy cover, and the diameter at breast height (DBH) for all woody stems greater than 5 cm that were found within 3 meters on either side of the transect tape. Any woody species observed in the polygon, but different from the species along the 6 meter corridor of the transect tape, were recorded as "additional species". Cover data was extracted as follows: the point where an imaginary vertical line drawn from the edge of a tree or shrub's canopy to the transect tape intersected the ground represented the start point for that species. Similarly, the end point was determined at the point where the transect tape exited the cover provided by that species. In cases where several different canopy layers covered the tape at the same location, the start and stop points were recorded for individual species and recorded as canopy or sub-canopy.

When the canopy extended beyond the beginning or the end of each transect, the distance between the end of the tape and the edge of the canopy was measured or estimated and added to the data.

Herbaceous Vegetation: Species diversity and percent cover were estimated using 0.25 m^2 plots (0.71m x 0.355m, rectangular Daubenmire frames). The plot frame was placed every 5 meters along the transect centerline. Herbaceous cover classes were standardized as follows:

R	<<1percent
+	< 1percent
01	1-5percent
02	5-25percent
03	25-50percent
04	50-75percent
05	75-100percent

Exotic/Invasive Species: Particular attention was given to mapping and/or otherwise noting the presence of invasive species such as tree of heaven, (*Ailanthus altissima*), scarlet wisteria (*Sesbania punicea*), tree tobacco (*Nicotiana glauca*), and tamarisk (*Tamarix* spp.), etc. These and giant reed (*Arundo donax*) and other troublesome herbaceous exotics were indicated on field copies of the aerial photos, or noted in transect data.

Analyses

Data was compiled in Excel spreadsheets and analyzed with Statistica software. There were 13,124 meters of transect data examined. Factors included in the analysis were: cover types, average polygon size, total areal extent of various habitats in each reach, canopy coverage of tree species, size-class profiles and importance values of woody stems (basal area, frequency of occurrence in the transect belts, and density), cover of herbaceous species, species diversity, distance between levees or confining bluffs, and river mile.

RESULTS

Description of Habitats

Cottonwood Riparian

As described in Holland (1986) Great Valley Cottonwood Riparian Forest (Holland type #61410) is a dense, broad-leaved deciduous forest found on fine-grained alluvial soils that are usually flooded on a yearly basis. Dominant species are Fremont cottonwood (*Populus fremontii*) and Gooding's black willow (*Salix goodingii*); other willow species include red willow (*S. laevigata*) and arroyo willow (*S. lasiolepis*). Box elder (*Acer negundo*) and ash (*Fraxinus latifolia*) are also commonly found in this vegetation type.

In older stands the cottonwoods form a high canopy, reaching heights of 40-60 feet, with the other species forming a mid-level canopy and understory. The understory is typically dense with young willows and cottonwoods (Hink & Ohmart class #1). Other understory

species include wild rose (*Rosa californica*) and the introduced Himalayan blackberry (*Rubus discolor*). Some older or grazed stands have little woody undergrowth (H &O #2); understory vegetation may consist of grasses or herbs such as mugwort (*Artemisia douglasiana*).

A more open variation of the cottonwood riparian community (Cottonwood riparian LD) can be observed on gravelly stretches of the channel, where the cottonwoods and willows may be widely scattered with little understory vegetation. Tree cover is less than 50 percent. Individual trees may range from 10 to 50 feet or more in height, covering H&O classes 2, 4, and 6. Such stretches are often invaded by non-native weedy vegetation such as eucalyptus and giant reed (*Arundo donax*), and the open nature of the vegetation is probably maintained by disturbance.

Willow Riparian. This is a subtype of Holland's Great Valley Cottonwood Riparian Forest. Many areas along the San Joaquin are dominated by willows, frequently almost exclusively by black willow. Red willow and arroyo willow may also appear. Occasional scattered cottonwoods, ashes or alders may be present but are never an important part of the canopy cover. Usually cover is dense, and most of these polygons are classed as H&O 3 or 4 (sometimes 1 or 2). Buttonwillow (*Cephalanthus occidentalis*) is often present and may even dominate the riverbank for stretches.

Willow Riparian Low Density (LD) consists of scattered trees or small clumps of trees, with <50 percent cover overall, and (usually) H & O class 4 or 6.

Willow Scrub

Sand and gravel bars in the more disturbed areas of the open channel frequently support open to dense shrubby stands of willow vegetation less than 15 feet in height. This plant community fits Holland's description of Great Valley Willow Scrub (Holland type #63410). These sites are subject to deeper flooding and higher flows, burying and breaking of woody stems. Gooding's black willow and narrow-leaved willow are able to bend with the flows and recover, or resprout from the base. They are the most common dominants, with the narrow-leaved willows frequently forming dense clonal stands. Cottonwood seedlings are usually present but rarely reach reproductive size. Willow scrub is usually classed as 5 or 6 in the H & O system; with the more open scrub falling into the 6 category. Buttonwillow is also a common component of this habitat.

Riparian Oak

Areas with valley oak that is dominant or co-dominant fall into this category, described by Holland as Valley Oak Woodland (Holland type #71130). Typically polygons dominated by oak are older stands and will be classed as H & O 1 or 2, with some 3 and 4 areas. Open woodlands with only valley oak trees and grassy understory are typical of areas farther away from the active channel; more mixed types occur nearer the water, with scattered willows and sycamores. A valley oak/sycamore co-dominated type is found along the lower edges of the bluffs along the upper river, in Reach 1a. These are very tall old trees with understories including wild rose, blackberry, and elderberry as well as various herbs.

Mixed Riparian

Mixed riparian communities form under conditions of less disturbance/flooding than the willow and cottonwood riparian communities, usually somewhat further back from the active channel. Dominants change along the river, with some areas heavily dominated by ash, while others are very mixed. Willows are usually present, and other species include valley oak (*Quercus lobata*), black walnut (*Juglans hindsii*), alder (*Alnus rhombifolia*), sycamore (*Platanus racemosa*), and cottonwood (*Populus fremontii*) in various proportions. Vegetation is typically dense, with an H & O class of 1 or 3. This type is most common along the upper reaches of the river.

Herbaceous

Generally, annual grasslands in the study area intergraded with communities dominated by annual forbs and biennial or perennial herbs. These contained varying percentages of native elements, sometimes as native perennials such as *Leymus triticoides.* Herbaceous communities comprise the dominant vegetation type throughout the study area, occupying between 26 to 86 percent of the total mapped natural habitat. Some areas may intergrade with seasonal wetlands. This community corresponds most closely with Holland's Non-native Grassland (Holland type #42200), and may include, at times, his Valley Wildrye Grassland (Holland type #42140), in areas with dense *Leymus triticoides*, or Valley Sacaton grassland (Holland type #42120), in areas with *Sporobolus airoides.* Both of these latter types are frequently found in the less levee-confined, higher-water table public lands of Reaches 4 and 5.

Riparian Scrub

Riparian scrub as defined here consists of a couple of species associations that are each fairly common. One is dominated by mugwort (*Artemisia douglasiana*) together with nettle (*Urtica dioica*) and various tall weedy herbs; the other is either blackberry (usually the introduced *Rubus discolor*) or wild rose (*Rosa californica)* in dense thickets, with or without scattered small emergent willows. No description in Holland's classification matches either of these vegetation associations, but they are very commonly encountered along the San Joaquin River, especially in the highly channelized reaches. Such ruderal associations may be maintained by periodic disturbance, i.e. flood control clearing of woody vegetation.

Riverwash

This community is almost strictly herbaceous, a very dry formation in the summer, on well-drained cobbles and gravels of the river bottom or high (and dry) sandbars. The species list is similar to that of the herbaceous habitat, with the prominent additions of California poppy (*Eschscholzia californica*) and bush lupine (*Lupinus albifrons*). These are the first areas colonized by willow scrub, and also the first to be scoured by high flows. The frequent disturbance and poor substrate quality allow very little vegetation establishment, resulting in a mostly bare substrate.

Wetland/Marsh

Because of the difficulty in distinguishing various wetland types on the aerial photos, and the confounding factor of a wet year, this catch-all designation includes both Holland's Coastal and Valley Freshwater Marsh (52410) and also Vernal Marsh (52500) and even Vernal Pools (44000). Typically wetlands occur in the river bottom immediately adjacent to or separated by just a few meters from the low-flow channel. They are most abundant in Reaches 4b and 5. Sites like backwaters and sloughs where water is present through much of the year support emergent marsh vegetation such as tules (*Scirpus acutus* var. *occidentalis*) and cattails (*Typha* spp.). More ephemeral wetlands, especially along the margins of the river and in swales adjacent to the river, support an array of native and introduced herbaceous species including western goldenrod (*Euthamia occidentalis*), arrowgrass (*Pluchea odorata*), smartweed (*Polygonum* spp.), Mexican rush (*Juncus mexicanus*), horseweed (*Conyza canadensis*), willow herb (*Epilobium brachycarpum*), saltgrass (*Distichlus spicata*) sunflower (*Helianthus annuus*), and curly dock (*Rumex crispus*). In Reaches 4 and 5, slim aster, (*Aster subulatus* var. *ligulatus*), pitseed goosefoot (*Chenopodium berlandieri*), alkali mallow (*Malvella leprosa*) and evening primrose (*Oenothera elata*) are commonly encountered in addition to the above species.

General Description of Reaches

Reach 1 (River Mile 229 to 267)

This reach extends from Gravelly Ford (RM 229) to Friant Dam (RM 267). This is the longest defined reach in our study area, and for some analyses it is broken into two subreaches: Reach 1a, from Friant Dam to the Highway 99 bridge at Herndon, and Reach 1b, from Gravelly Ford to the Highway 99 bridge.

Sub-Reach 1a (RM 243 to 267) has the highest flows during late summer and fall, the greatest diversity of vegetation types, and has the highest overall diversity of plant species. It is also the most urbanized region of the project area, and has more gravel extraction and the least number of confining levees of any of the reaches. Steep bluffs confine the riparian zone over much of Reach 1a.

Riparian oak forest and mixed riparian forest are more commonly encountered in Reach 1a than downstream. In decreasing order of areal extent, the natural habitat types found here are: herbaceous (2701 acres), mixed riparian forest (526 acres), riparian oak forest (289 acres), willow scrub (290 acres), wetland/marsh (247 acres), willow riparian (233 acres), riparian scrub (71 acres), exotic tree (55 acres: mostly eucalyptus, tree of heaven, mulberry and fig), riverwash (33 acres), *Arundo* (3 acres) and elderberry savanna (2.3 acres). Herbaceous and exotic vegetation types account for two-thirds (66.8 percent) of the total natural vegetation mapped, while approximately one-quarter (26.8 percent) is riparian forest. Woody scrub makes up less than seven percent (6.5 percent) of the total natural vegetation. The ratio of habitat per river mile is 194.2 acres/mi. See Figure 2.

In addition to the woody exotic trees and giant reed mentioned above, scarlet wisteria (*Sesbania punicea*) is widespread in portions of Reach 1a, and is currently the focus of

eradication efforts by local community groups. It has invaded wide areas of the floodplain in this and the subsequent Sub-Reach 1b, displacing willow scrub along the edge of the low-flow channel.

Sub-Reach 1b (RM 229 to 243) is more narrowly confined by levees than the previous section. The proportion of herbaceous and exotic vegetation is closer to one-half of the total natural vegetation (55 percent), and the proportion of woody riparian vegetation is closer to one-third (30.6 percent) of the total, and occurs mainly in narrow strips immediately adjacent to the river channel. Willow scrub is more abundant (14.3 percent) than in Sub-Reach 1a. Outside the levees and steep bluffs, the land use is nearly all agricultural. Scarlet wisteria was observed as far downstream as river mile 240. Giant reed patches are commonly encountered. The most abundant habitat types are herbaceous (300 acres) and mixed riparian (280 acres), followed by cottonwood riparian (193 acres), willow scrub (155 acres) and willow riparian (120 acres), then approximately equal acreages of riparian scrub (47.9 acres) and riverwash (47.1 acres). See Figure 3. This sub-reach has the second lowest ratio of natural vegetation per river mile—in 14 miles of channel, there is a little over one square mile of natural habitat (677 acres, or 48 acres per mile).

Reach 2 (RM 205 to 229)

This reach continues from Gravelly Ford to Mendota Pool and is characterized by seasonal drying in the late summer and fall. The water table recedes into the porous substrate, creating a pronounced riparian drought nearly every year. There is about half as much riparian forest, proportionally, as in Reach 1 (15 percent of natural and naturalized vegetation), about the same proportion of woody scrub communities (13.5 percent) as Reach 1b, and more herbaceous vegetation (71 percent) than in Reach 1 overall. The most abundant habitat type by far is herbaceous (718.7 acres), followed by riparian scrub (302.8 acres), willow scrub (254.2 acres), riverwash (173.8 acres), willow riparian (165.4 acres), cottonwood riparian forest (124.5 acres), elderberry savanna (65.7 acres; the only significant stand of this vegetation type found in our study), exotic tree (8.9 acres) and *Arundo* (5.8 acres). A smattering of mixed riparian forest (1.73 acres) and riparian oak forest (0.48 acres) complete the inventory of habitat types found in this reach. See Figure 4. The ratio of natural vegetation/river mile is 79.0 acres/mi., about 60 percent higher than in Reach 1b, but 40 percent of that in Reach 1a.

Cultivated lands occupy nearly all the lands outside the river bottom. The character of the reach changes somewhat near Mendota Pool (RM 216-204). Downstream of the bifurcation structure at RM 216 (SW of which is found the large elderberry savanna), the riparian zone is very narrowly confined to a thin strip 3-10 meters wide bordering the channel. The herbaceous understory is however, very rich in native species and a high proportion of the total vegetative cover is native plants, possibly due to the exclusion of cattle and other domestic stock from these thin habitat strips.

Reach 3 (RM 230 to 135)

This reach starts at Mendota Pool and extends to Sack Dam. The reach is characterized by a continuous flow within a very confined channel, seasonally low water (although not

as dry as Reach 2), and narrow strips of riparian habitat along the river's edge. Adjacent lands are mostly under cultivation, although the city of Firebaugh borders the river's west edge for 3 miles. This reach has the smallest proportion of herbaceous habitat (25.2 percent) and the highest proportion of riparian forest (53.7 percent). Willow scrub occupies 21 percent of the total extent of natural vegetation. The most common habitat is cottonwood riparian, with 460.8 acres. Willow scrub occupies 230.5 acres; herbaceous vegetation covers 174.4 acres, willow riparian accounts for 124.8 acres, while riparian scrub totals 60.6 acres. Riverwash (22.5 acres), wetland/marsh (16.2 acres), exotic tree (0.44 acres) and *Arundo* (0.14 acres) are the least abundant habitat types. See Figure 5. Forty-seven and one-half acres of natural vegetation were mapped for every river mile in this reach, equivalent to the ratio found for Reach 1b.

Reach 4 (RM 136 to 182)

This reach extends from Sack Dam to the confluence with Bear Creek. It is subdivided into Sub-Reaches 4a and 4b for this analysis.

Sub-Reach 4a (RM 148 to182) originates at Sack Dam and continues into the southern portions of the San Luis National Wildlife Refuge, begins in cultivated and ends in public lands. Access for field verification and transects was denied in about half of this stretch. Reach 4a has the fewest habitat types and the lowest ratio of natural vegetation per river mile of any of the segments we examined—only 502 acres of vegetation are mapped in this 34-mile segment (14.8 acres/mi.). The proportion of herbaceous habitats is typical of the San Joaquin River as a whole—about two-thirds (67.7 percent), while the proportion of forest is 22.4 percent and the proportion of woody scrub is 5 percent. The most common habitat is herbaceous, with 177.2 acres. Willow riparian forest is the next most abundant (89.1 acres), followed by riverwash (65.2 acres), riparian scrub (56.7 acres), willow scrub (48 acres), wetland/marsh (40.9 acres), cottonwood riparian forest (19.3 acres), and lastly, mixed riparian forest (5.65 acres). No mappable stands of exotic trees or giant reed were found. See Figure 6.

Sub-Reach 4b (RM 136 to 148) continues through the public lands to the confluence with Bear Creek (RM 136). Cultivated fields border approximately nine miles of the river's eastern bank. The floodplain is broad between widely spaced levees and the water table is nearer the surface than in some of the other reaches. These factors, along with a much lower level of disturbance to the native landscape on the public lands, create vast areas of natural habitat, compared to the upstream reaches. Herbaceous vegetation makes up nearly three-quarters of the total (74.3 percent), riparian forest covers 12.1 percent of the total, and woody scrub makes up the remaining 13.6 percent. See Figure 7. The ratio of natural habitat per river mile increases thirty-five-fold over that of Reach 4a, with a similar ratio continuing to the Merced River confluence (512.8 acres/mi. in Reach 4b). The actual amount of natural habitat surrounding the river is even greater than this figure indicates, since the area mapped in this study was limited by the extent of the available aerial photography; which was limited to a narrow corridor (approximately 2000 feet) of the vast flood plain.

The most common habitat, in this reach, is clearly herbaceous vegetation (4175 acres), followed by willow riparian forest (701.2 acres), wetland/marsh (377.7 acres), willow

scrub (132.1 acres), riparian scrub (61.9 acres), cottonwood riparian forest (36.9 acres), exotic tree (15.7 acres), riparian oak forest (7.5 acres) and riverwash (5.8 acres). Giant reed was not seen in this reach.

Reach 5 (RM 118 to136)

This reach proceeds from the confluence with Bear Creek to the confluence with the Merced River. Eight miles of this reach are adjacent to cultivated lands on the eastern bank, while the rest is bordered by relatively undisturbed natural habitat of private duck clubs and State and federal lands designated as refuges and parks. Herbaceous habitats make up 86 percent of the natural vegetation in this reach, while forest comprises 12.2 percent and willow scrub 1.7 percent of the total. The natural habitat mapped per mile is similar to that of Reach 4b: 508 acres/mi. The characteristic habitat type of this reach is herbaceous vegetation, with 7,239 acres spreading over the wide floodplains of the San Luis Wildlife Refuge and the North Grasslands Wildlife Area. Following in predominance are willow riparian (972.6 acres), wetland/marsh (532.02 acres), willow scrub (86 acres), riparian scrub (82.7 acres), alkali scrub (70 acres), mixed riparian forest (69.12 acres), cottonwood riparian forest (36.25 acres), riparian oak forest (30.6 acres), exotic tree (11.6 acres), riverwash (7.6 acres) and giant reed, nearly absent with only 0.36 acres. See Figure 8. The amount of wetlands encountered in the 30 river miles of Reach 4b and Reach 5 total more than twice that contained in the 119 miles of Reaches 1 through 4a.

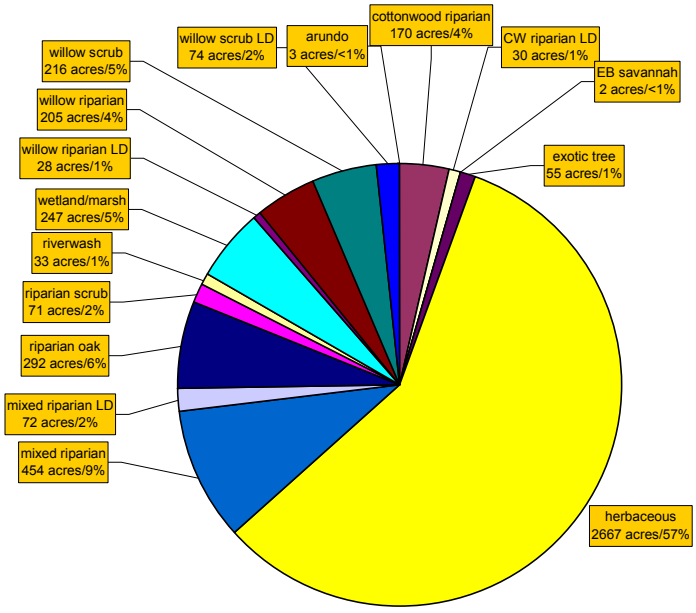


Figure 2. Reach 1a Vegetation Types

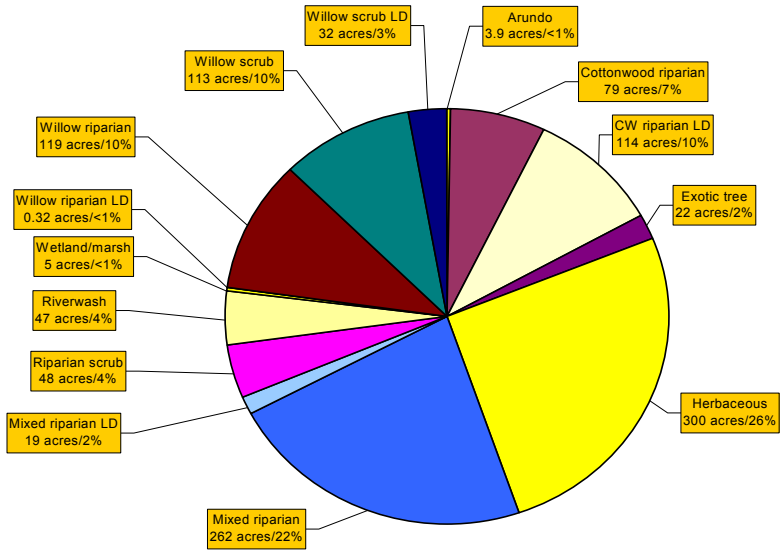


Figure 3. Reach 1b Vegetation Types

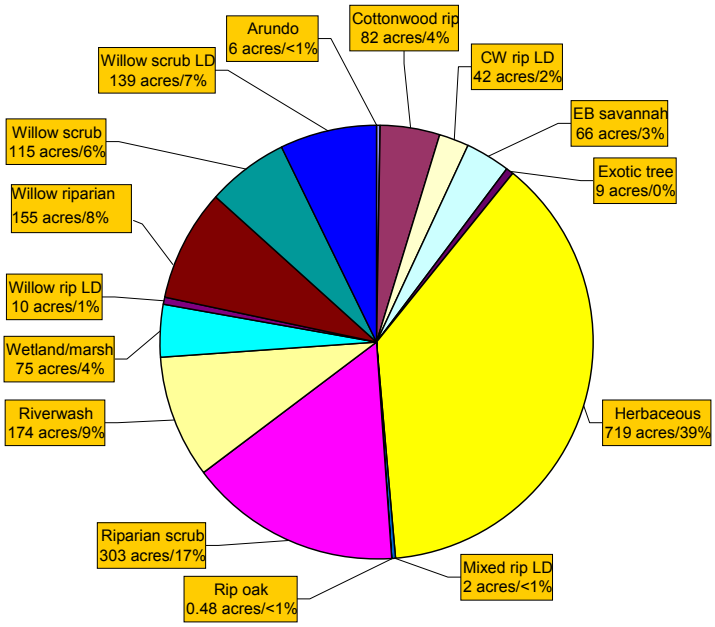


Figure 4. Reach 2 Vegetation Types

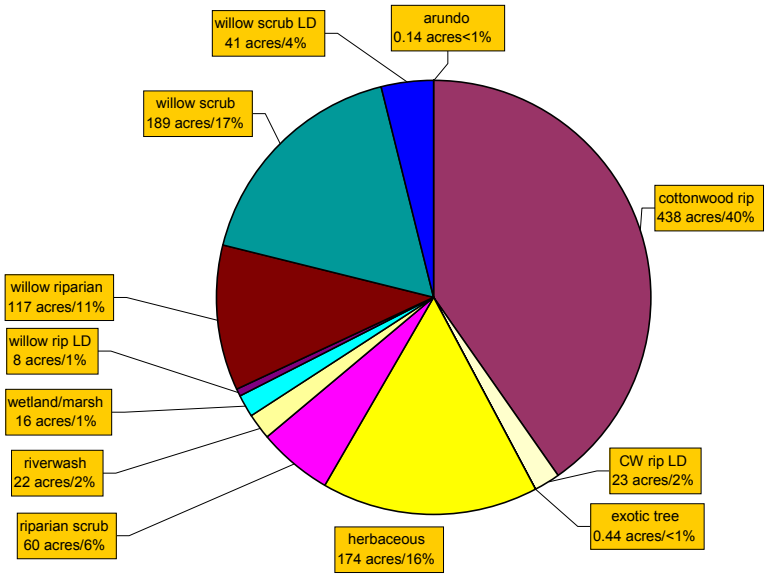


Figure 5. Reach 3 Vegetation Types

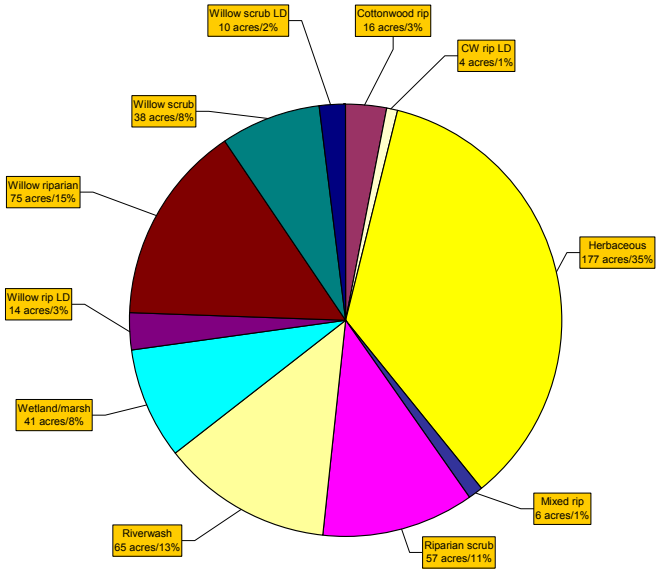


Figure 6. Reach 4a Vegetation Types

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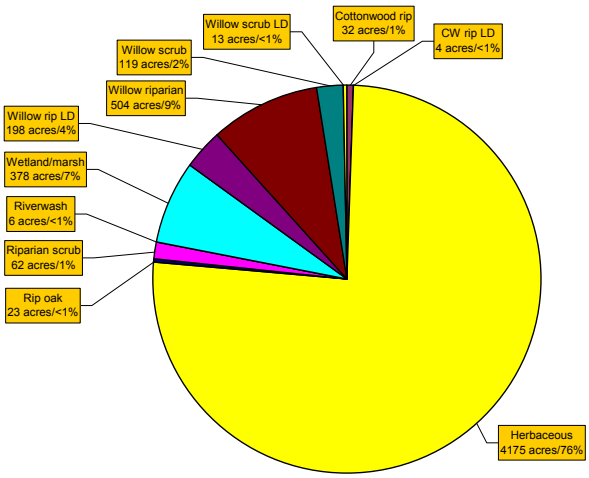


Figure 7. Reach 4b Vegetation Types

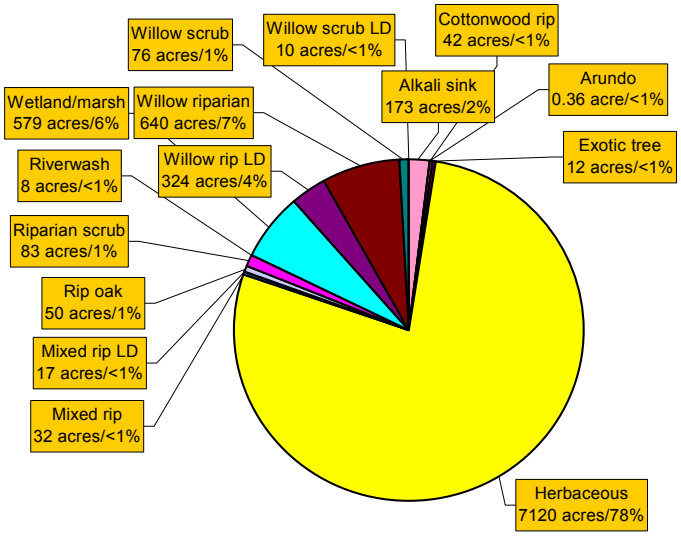


Figure 8. Reach 5 Vegetation Types

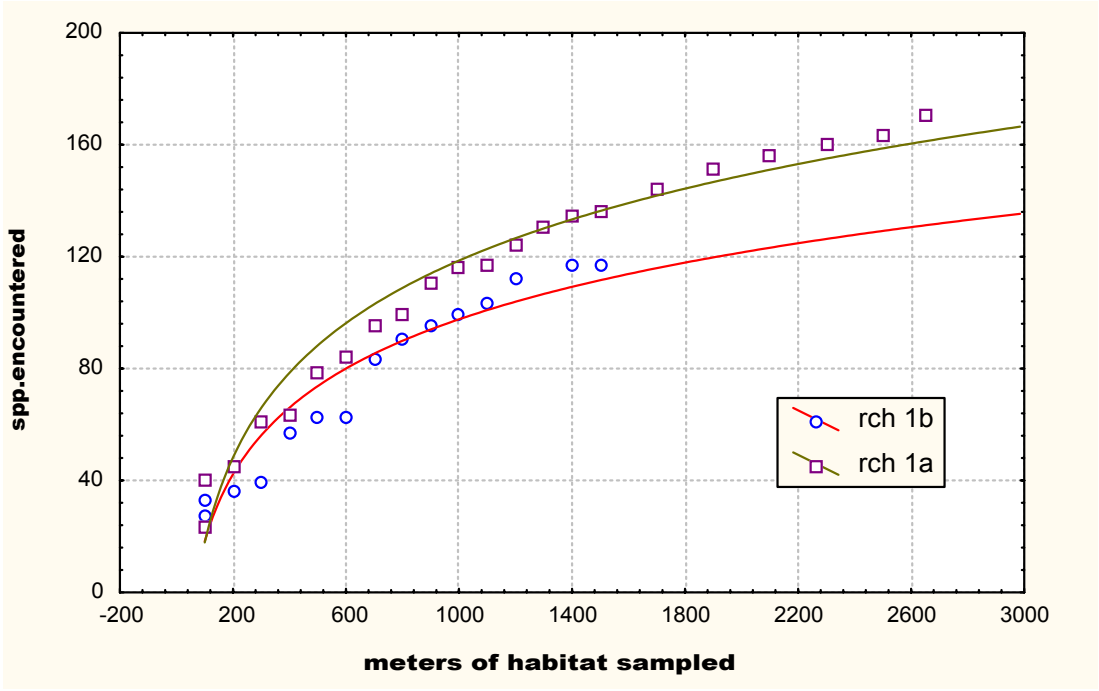


Fig 9. Reaches 1a (RM 243-267) and 1b (RM 229-243) rarefaction curves: meters of transect sampled vs. number of spp. observed.

Species Diversity

Plant species diversity for the project area totals 256 species in 151 distinct genera, classified in 61 families. Of these species, 129 (50.4 percent) are native. Life forms found include 18 tree species (12 natives and 6 introduced species), 2 shrubs, 4 vines, 14 aquatic herbs, and 218 other herbaceous species. Thirty-five of these species have broad ecological amplitude and are common to all the reaches, while 112 are confined to one reach exclusively, and 111 species are found in two-to-four of the five reaches. Reach 1 contains the most unique species (70 spp.), while Reach 5 has the fewest (2 spp.).

Reach 1 has the highest overall diversity of species, as well as the highest number of native species (although, interestingly, the lowest proportion of natives to non-natives): a total of 214 taxa, of which 105 species are native (49.1 percent). With 95 species, Reach 2 has less than half of the total number of species as Reach 1. In Reach 2, 55 species (57.9 percent) are native. Reach 3 has the highest proportion of native species: of 107 species total, 64 (59.8 percent) of them are native. Reach 4 has 113 species total, of which 65 (57.5 percent) are native, and Reach 5 has 92 species, of which 50 (54.3 percent) are native.

Rarefaction curves were prepared for each reach in order to estimate the total number of species present, beyond what we were able to observe. This technique incorporates the observation that with increasing effort, fewer and fewer species will be added to the list for a given area. By plotting transect meters examined against new species acquired, curves are obtained which can be used to predict the total number of species that would be found given unlimited resources. Representative curves for Reaches 1-3 are shown in figures 9 through 11. Appendix 5 contains rarefaction curves for the remaining reaches. As shown, the numbers predicted for total species diversity in each reach (depicted by solid lines) differ by only a few percent from the numbers actually observed. Consequently, we are confident that most species identifiable during the summer through early fall were observed. In Figure 10, the species total portrayed in the graph is higher than that in the text description because a number of distinguishable species were not identified to species and rarefaction was

generated on raw data points including such factors as litter and bare ground. For this analysis, rarefaction curves were generated for Sub-Reaches 1a (from Friant Dam to Herndon [RM 243-267]) and 1b (from Herndon to Gravelly Ford [RM 229-243]).

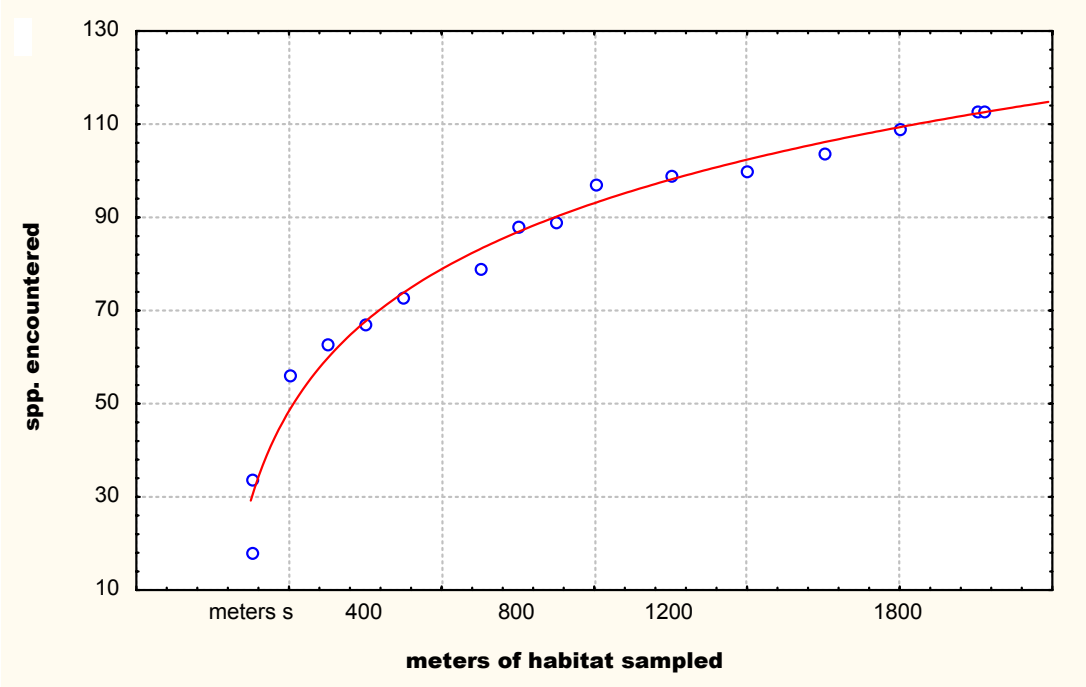


Fig 10. Reach 2 rarefaction curve: (RM 205-229)

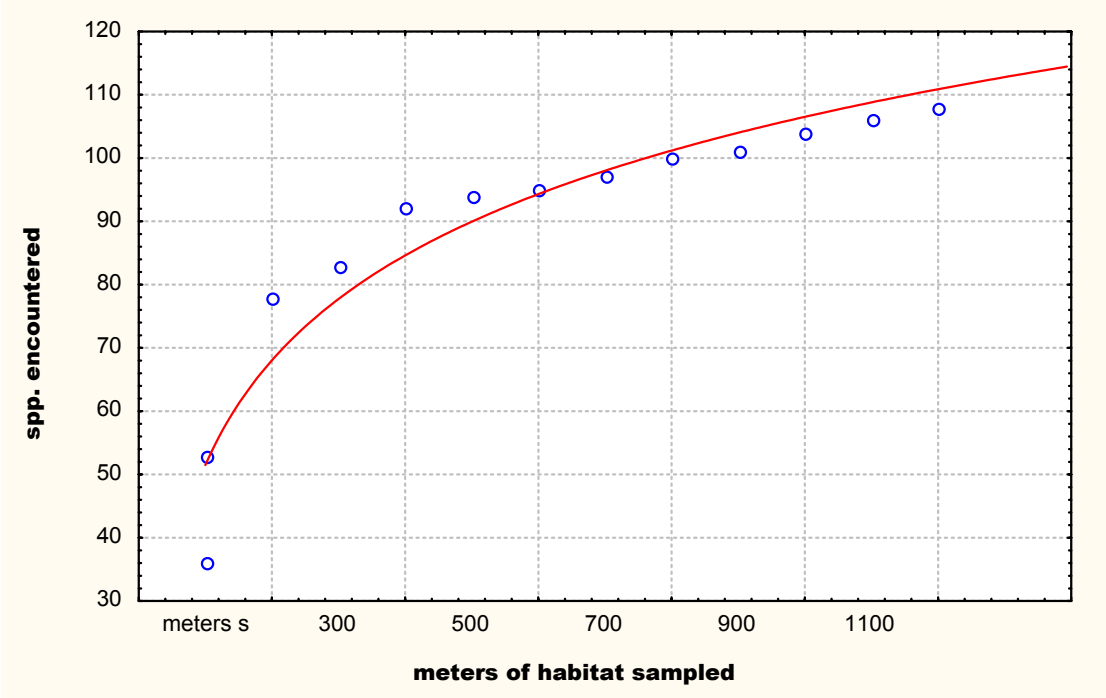


Fig 11. Reach 3 rarefaction (RM 182-205): x and y axes as above.

Woody Vegetation

Overall cover of woody species as estimated by line-intercept within the habitats sampled is summarized in the following table:

Table 2

Canopy and Understory Transect Summary					
	Total Transect Length (m)	Total Canopy Intercept (cm)	% canopy cover	Total Understory Intercept (cm)	% cover of understory spp.
REACH 1	4529.03	237941	52.54	73632	16.26
REACH 2	2135.50	63415	29.70	11628	5.45
REACH 3	1290.07	76827	59.55	19339	14.99
REACH 4	2999.60	69085	23.03	1125	0.38
REACH 5	2169.75	89391	41.20	10127	4.67
All Reaches:	13123.95	536659	40.89	115851	8.83

The figures in Table 2 overestimate woody cover in the riparian corridor, because we sampled uncommon vegetation types with greater frequency than they occurred, in order to characterize those particular habitats in some detail (by the relevé procedure, Elzinga et al, 1998). Woody cover as measured along transects totals 44 percent. However, vegetation polygons composed of forests and other woody riparian vegetation equals 24.8 percent of the total mapped riparian vegetation. About 9.5 percent of the total transect length is covered by vines and other understory (sub-canopy woody species), particularly Himalayan blackberry (*Rubus discolor*), California rose *(Rosa californica*), buttonbush (*Cephalanthus occidentalis*) and juvenile or small members of the canopy species.

Importance Values

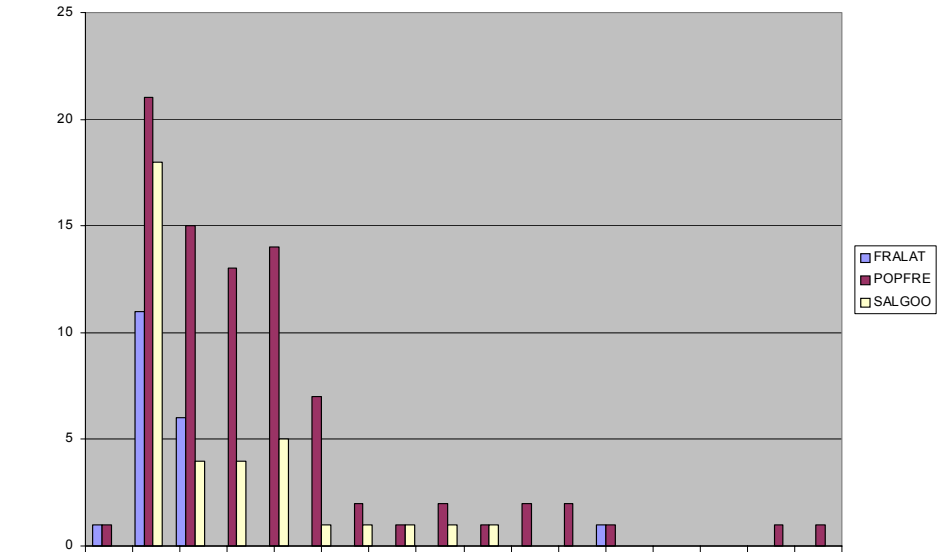
Importance values for woody species were calculated for each species in specific habitat types in each reach. The formula sums relative cover of each species as a percentage of total woody cover with relative density of stems and relative frequency of occurrence in each transect segment. The importance value is given as a percentage, which can range from 0 to 300 percent. Frequency of occurrence was calculated two ways: 1) by frequency of stems (from the DBH data in each 6-meter wide transect belt), and 2) by frequency of occurrence in line-intercept data for each transect segment. The rankings of importance values generated for each species in a given habitat type were identical in most cases, although rankings did shift occasionally (see Appendix 3—Importance Values, Reaches 1-5).

The most common species in the top three ranks are: Black willow (*Salix goodingii*), which consistently ranked high in habitats in all reaches (47 occurrences in ranks 1 or 2); sandbar willow (*Salix exigua*), with 19 occurrences in the top 2 ranks, again found in the top two ranks in all reaches; and Fremont cottonwood (*Populus fremontii*), which ranked first or second in at least one habitat in all reaches (15 occurrences in ranks one or two

over all reaches). Buttonbush (*Cephalanthus occidentalis*) occurred in the top two ranks in four of the five reaches a total of 12 times. Oregon ash (*Fraxinus latifolia*) made the top ranks in Reaches 1 and 2 only (in Reach 2 only once), for a total of 4 occurrences in the top two ranks. Sycamore (*Platanus racemosa*) is a significant presence only in Reach 1 (reaching the top rank twice and the third rank once). Valley oak (*Quercus lobata*) occupies the top ranks only in Reaches 1, 4 and 5, for a total of eight occurrences in the first and second ranks.

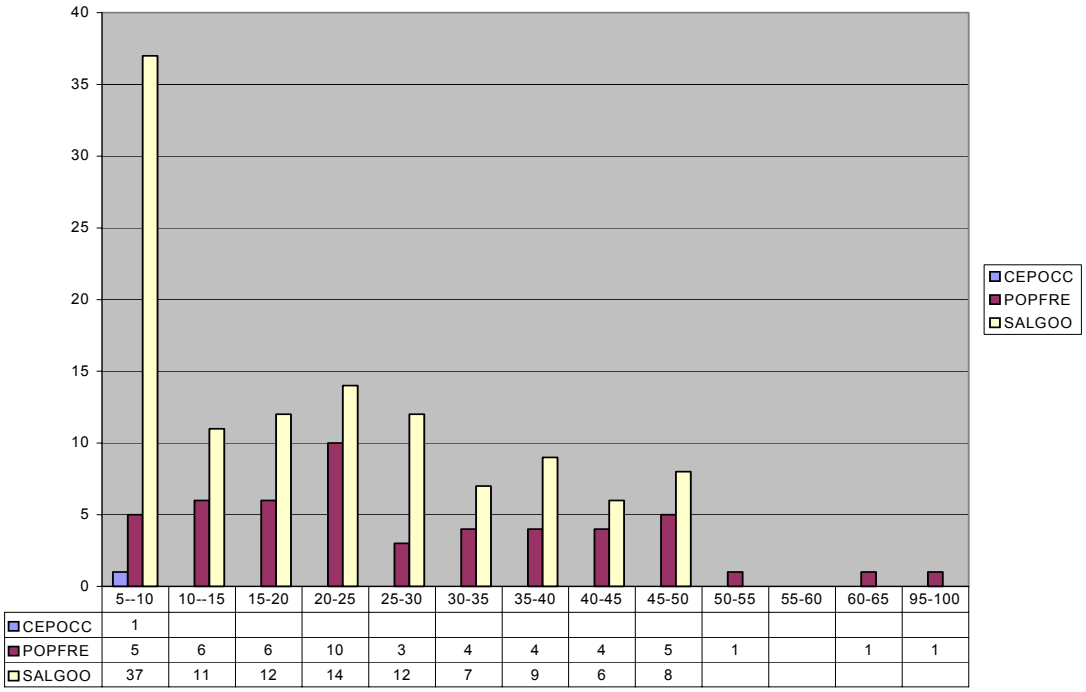
Size-Class Data

Diameter at breast height (DBH) of all woody species in the transect belt within a habitat type were measured with standard metal DBH tapes. The size class distributions of these stems within habitat types for all reaches are given in Appendix 4. A classic example of size class distribution is Figure 12, which shows declining numbers of stems with increase in girth. (For this study, size classes were designated within a range of 5 centimeters in the respective size class, noted on the x-axis in figures 12-14.) Generally, this is interpreted to signify more-or-less steady recruitment and mortality of younger stems, as they age and succumb to drought, disease, scour, etc. This example shown in Reach 1, from cottonwood riparian forest (summed over all Hink and Ohmart structural classes), could be interpreted this way. By contrast, the size class distributions shown in Figure 14 taken from cottonwood riparian forest in Reach 5, portray a different situation. These data probably indicate episodic recruitment of these species. Alternatively, although less likely, these results may indicate different growth rates in different parts of the reach. Coring or sectioning of stems would distinguish between the two scenarios.



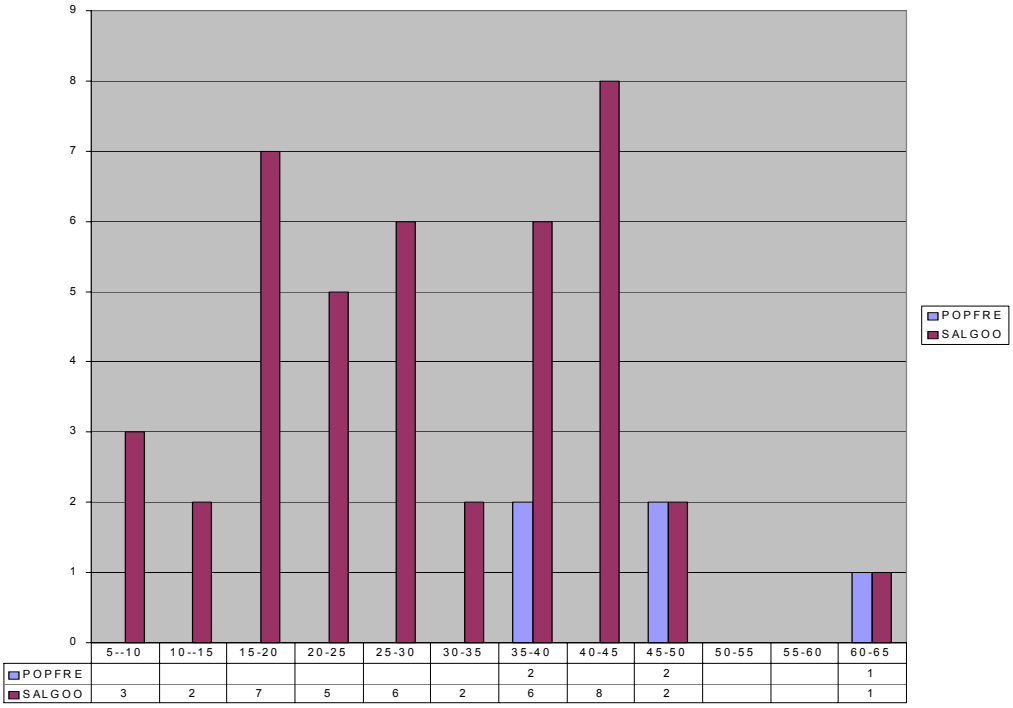
	<5	5--10	10--15	15-20	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	70-75	75-80	80-85	85-90
FRALAT	1	11	6									1				
POPFRE	1	21	15	13	7	2	1	2	1	2	2	1			1	1
SALGOO		18	4	4	1	1	1	1	1							

Fig 12. Size-class distribution in cottonwood riparian forest in Reach 1. (X-axis is in cm.)



	5--10	10--15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	95-100
CEPOCC	1												
POPFRE	5	6	6	10	3	4	4	4	5	1		1	1
SALGOO	37	11	12	14	12	7	9	6	8				

Fig 13. Size-class distribution in cottonwood riparian forest in Reach 3. (axes as in Fig. 5).



	5--10	10--15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65
POPFRE							2		2			1
SALGOO	3	2	7	5	6	2	6	8	2			1

Fig 14. Size-class distribution in cottonwood riparian forest, Reach 5 (axes as above).

Herbaceous Species

Diversity

The diversity of herbaceous species in the major habitat types, along with the diversity found in the various Hink and Ohmart structural classes of each type, is given in Table 3. Cottonwood riparian forest (169 spp.), willow riparian (156 spp.), and herbaceous (133 spp.) habitats exhibit the highest numbers of herbaceous species encountered in our study area. Wetlands (69.2 percent), riparian scrub (62.2 percent), and willow scrub (59.2 per cent) show the highest proportions of native herbaceous species.

Chi-square values were calculated for number of native species expected (expected is generated as average number of natives found in each category—whether reach, habitat type, Hink and Ohmart class, etc.). This procedure showed significant differences in numbers of natives in different Hink and Ohmart structural classes, between habitat types per reach, between reaches, between habitat types summed across reaches, and between habitat types when partitioned by Hink and Ohmart class. All chi square values were significant at the $p<0.001$ level. (See Appendix 5 for calculations.)

Weighted species diversity indices (Shannon-Weiner index, Sokal and Rolf, 1981) were calculated for herbaceous species by reach, by habitat type, and by Hink and Ohmart structural class. Figure 15 shows diversity indices for herbaceous species by reach. A weighted diversity index such as the Shannon-Weiner incorporates both richness and equitability of occurrence. By this measure, Reaches 4 and 5 show the highest herbaceous diversity (both native and total), even though Reach 1 has the highest total number of species (214), and Reach 3 has the highest proportion of natives.

Weighted diversity indices were also calculated for habitats by reach. In all reaches, cottonwood riparian (when present), herbaceous and willow riparian habitats show the highest Shannon-Weiner values. (See Appendix 5 for details.)

Other analyses examined the richness of native and herbaceous species as a function of river mile or corridor width (distance between levees or confining bluffs), and the amount of native herbaceous cover as a function of river mile or corridor width. The only statistically significant correlation found was between river mile and native cover. See Figure 16. The significance of this relationship is genuine—the reasons are as yet, unclear. It is possible that native herbaceous plants are better adapted to the salinity/alkalinity of soils and water in the downstream reaches. In any case, the less disturbed, open, and less confined public lands of the wildlife refuges and parks of Reaches 4 and 5 support higher cover of native species. Large confinement width (and thereby, likelihood of more "natural" flooding) in our analyses, however, shows only a very weak relationship to proportion of native cover. See Figure 17.

Figure 19 shows a weak correlation exists between river mile and herbaceous species richness, consistent with higher Shannon-Weiner indices of diversity for Reaches 4 and 5. Although Reach 1 has the highest overall species diversity, Shannon-Weiner values were lower there than downstream. Perhaps in the lower reaches, alpha diversity, or the diversity in a small habitat area is higher, while in the upstream reaches the diversity summed across habitats and different segments of the river is higher.

Table 3 Habitat Types and Species Diversity

VEG TYPE	EXOTIC	NATIVE	TOTAL	%NATIVE
ARUDON	**1**	**0**	**1**	**0.00**
CW1	41	49	90	54.44
CW2	45	54	99	54.55
CW3	45	54	99	54.55
CW4	26	37	63	58.73
CWLD2	15	20	35	57.14
CWLD4	8	12	20	60.00
CW TOTAL	**70**	**99**	**169**	**58.58**
DISTURB	**17**	**21**	**38**	**55.26**
HERBAC	**57**	**76**	**133**	**57.14**
MR1	8	6	14	42.86
MR2	18	6	24	25.00
MR3	26	30	56	53.57
MR4	18	18	36	50.00
MRLD1	9	20	29	68.97
MRLD4	12	18	30	60.00
MR TOTAL	**42**	**50**	**92**	**54.35**
RIPOAK2	32	29	61	47.54
RIPOAK4	17	10	27	37.04
RIPOAK TOTAL	**35**	**32**	**67**	**47.76**
RIPSCR	**31**	**51**	**82**	**62.20**
RIVWAS	**31**	**36**	**67**	**53.73**
WETLAN	**20**	**45**	**65**	**69.23**
WR1	10	13	23	56.52
WR3	45	54	99	54.55
WR4	39	61	100	61.00
WRLD4	41	53	94	56.38
WR TOTAL	**65**	**91**	**156**	**58.33**
WS5	32	54	86	62.79
WS6	30	40	70	57.14
WSLD4	10	11	21	52.38
WSLD6	13	17	30	56.67
WS TOTAL	**49**	**71**	**120**	**59.17**

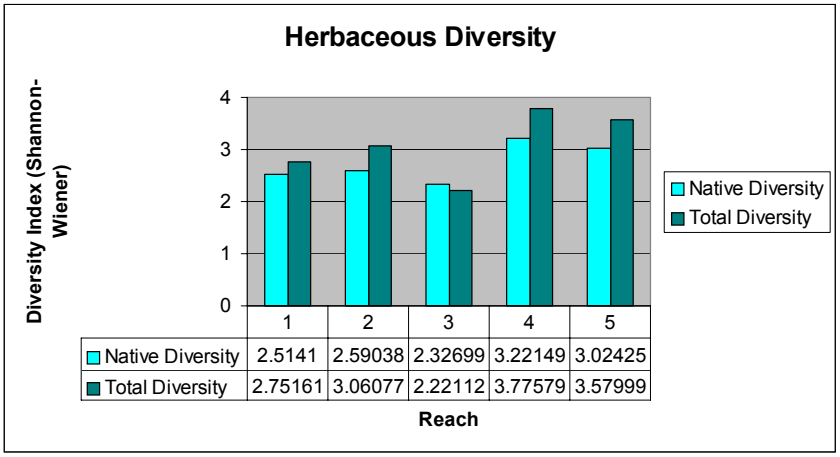


Figure 15. Weighted Diversity Indices for Herbaceous Species

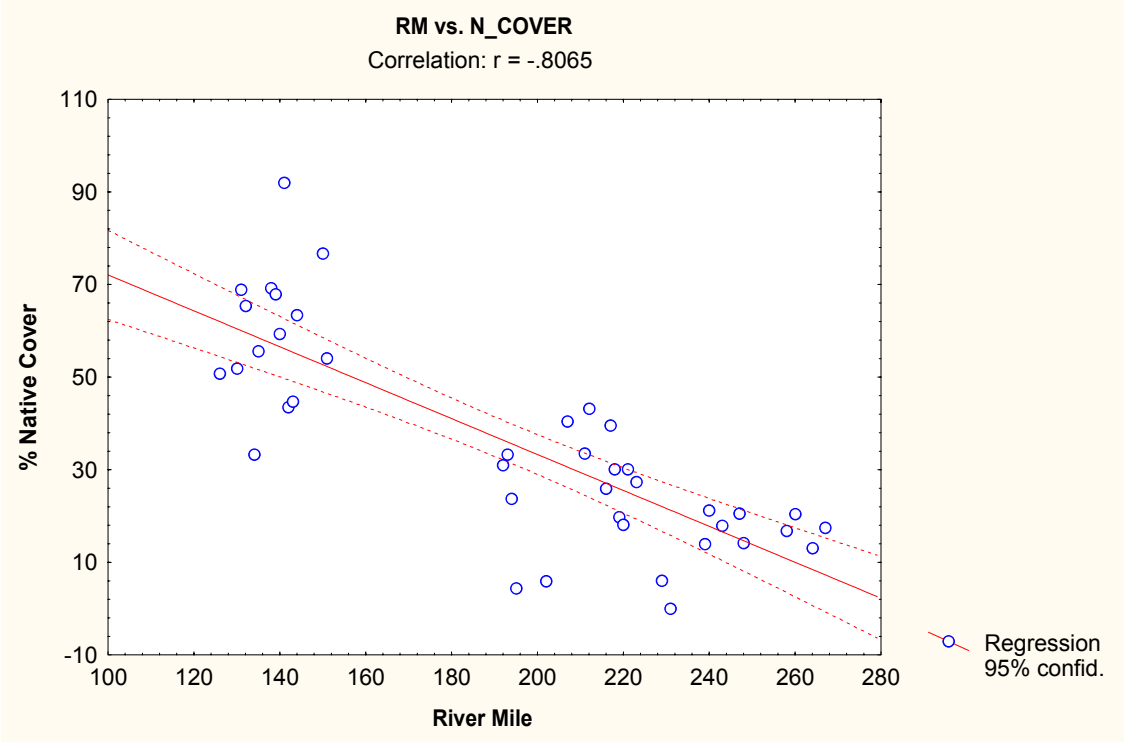


Fig 16. Proportion of native cover as a function of river mile.

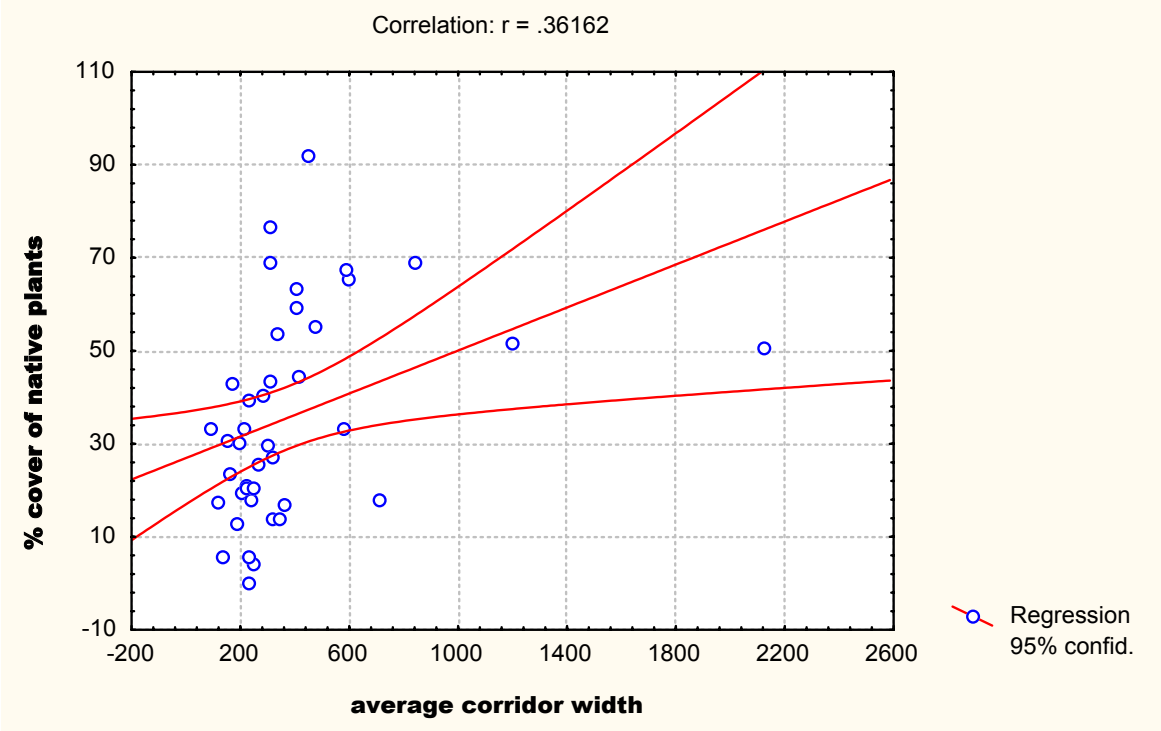


Fig 17. Proportion of native cover as a function of levee/bluff confinement width.

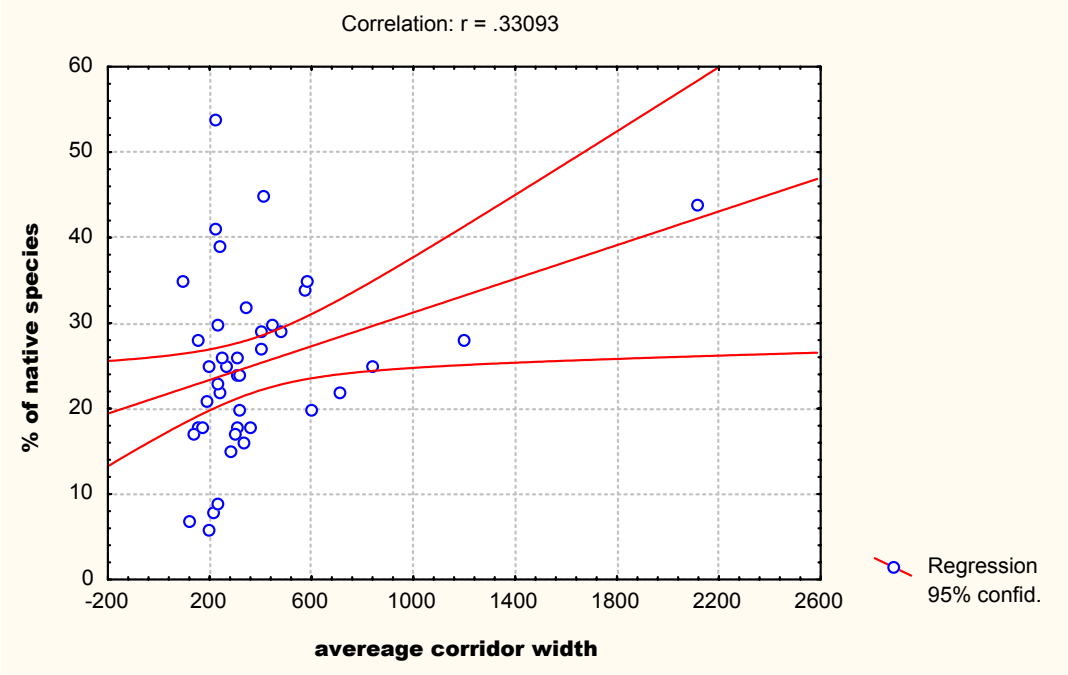


Figure 18. Proportion of native spp. as a function of levee/confinement width.

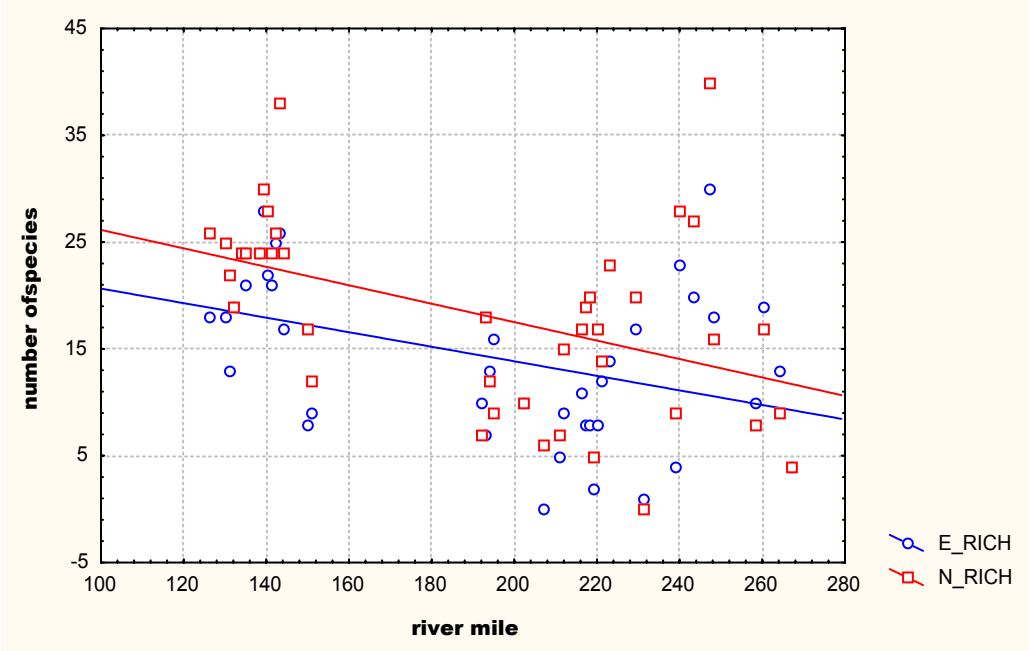


Figure 19. Species Richness per River Mile (Natives are red squares; exotics are blue circles)

Exotic Species

Weedy invasive species encountered in this study included giant reed (*Arundo donax*), tree-of-heaven (*Ailanthus altissima*), pampas grass (*Cortaderia* sp.), eucalyptus (mostly *E. globulus*), edible fig (*Ficus carica*), white mulberry (*Morus alba*), Lombardy poplar (*Populus nigra* var. *italiana* and various hybrids), castor bean (*Ricinus communis*), Himalayan blackberry (*Rubus discolor*), scarlet wisteria (*Sesbania punicea*), and tamarisk (*Tamarix pentandra*).

Giant reed

Arundo donax is one of the most problematic invasive species on many riparian systems in California. A member of the grass family, it reproduces clonally and has not been observed to set viable seed in California. It forms large monospecific stands that outcompete all other vegetation on disturbed sites. These stands are up to about 4 meters tall and are very dense. The California Exotic Pest Plant Council (CalEPPC) includes this species on its A-1 list of "Most Invasive Wildland Pest Plants; Widespread". In our transects, we found no other plant species within the giant reed clumps, and the clumps provide little habitat value for wildlife. *Arundo* was seen in all reaches except Reach 4; it is most abundant on Reach 2 and Sub-Reach 1a between Friant Dam and the Hwy. 99 bridge. We mapped 17.46 acres on Reach 2 and 16.41 acres on Sub-Reach 1a. There were an additional 6.96 acres on Sub-Reach 1b, but only small amounts (1/4 acre or less) detected on the other reaches. The larger acreages of Arundo on the weed layer as compared to the vegetation layer stem from the different minimum mapping units, since only the larger stands were mappable on the vegetation layer, or were indeed even detectable on the aerials.

Tree-of-heaven

This sadly mis-named species from Asia is another problematic weed in riparian systems and in other Central Valley habitats. It is fast growing and spreads both by seed and by suckering from the root system, and can form large clonal stands. It is considered by CalEPPC as list A-2 "Most Invasive Wildland Pest Plants; Regional."

Tree-of-heaven was found in Reaches 1 and 2, and was most abundant in Sub-Reach 1a with almost 3 acres recorded. Only about ½ acre each was found on Sub-Reach 1b and Reach 2.

Pampas grass

Pampas grass (probably *Cortaderia selloana*) is another list A-1 weed according to CalEPPC. It is found in many habitats in coastal areas but seems limited to riparian areas in the interior. It is commonly used as a landscape plant and spreads easily by means of many thousands of tiny, wind-blown seeds from the large plume-like inflorescences. Each individual forms a large clump up to several meters in diameter and about 3 meters in height.

Only two occurrences of this weed were noted on the San Joaquin River, thus it appears not to be widespread at this time. One occurrence was found in each of the Reach 1 sub-reaches.

Eucalyptus

Eucalyptus globulus is the most common of the several species in this genus that have become naturalized and weedy, and is considered a list A-1 plant by CalEPPC. It seeds readily and grows quickly, producing an oily litter that is suspected of inhibiting the germination and/or growth of other species (including natives) underneath it. It can take over riparian corridors, crowding and shading out other species.

Eucalyptus were widespread on the river, occurring in all reaches except 3 and 4. Almost 85 acres were recorded in Sub-Reach 1a, and 32 acres in Sub-Reach 1b. Reach 2 had 7 acres and Reach 5 had 12.3 acres.

Himalayan blackberry

Rubus discolor was introduced from Eurasia, and is listed as an A-1 weed by CalEPPC. It is extremely widespread in California, and appears to have widely usurped the ecological niche of its native relative, *Rubus ursinus* (California blackberry). It grows very vigorously and forms large, impenetrable clumps. The seeds are probably spread by birds or other wildlife.

Only one occurrence of this species was mapped (in Sub-Reach 1a), but due to the difficulty in distinguishing it from the native blackberry, *Rubus ursinus*, without relatively close examination, we did not continue to single it out for attention. It was very commonly observed during the transect fieldwork. Most of the blackberry along the river appears to be this species, particularly in the riparian scrub habitats where it lines the banks of the channelized river for long stretches. Eradication of this weed is probably not feasible. It does provide some habitat value for wildlife.

Scarlet wisteria

This plant is an up-and-coming invasive, with populations well established in the Sacramento and San Joaquin riparian zones. CalEPPC considers it a "Red Alert" species with the potential to spread explosively. It is a shrub with lovely red flowers, and hence is planted for landscape uses. *Sesbania punicea* is in the bean family, and produces prolific amounts of large seeds.

We found scarlet wisteria mainly along Sub-Reach 1a, extending downstream as far as river mile 242 in Sub-Reach 1b. It forms dense colonies on disturbed areas, sand and gravel bars, displacing the native willow scrub vegetation in these areas.

Other species

Other exotic species that were noted, including edible fig, white mulberry, Lombardy poplar, castor bean, and tamarisk, were limited to only a few small occurrences and are not considered to be major weed problems in this system at this time. However, Tamarisk is a well-documented invasive species in other systems and its distribution in this system should be monitored.

Comparison of Reaches

Overall, Sub-Reach 1a was by far the weediest of all the reaches studied, with over 122 acres of weeds documented through the field surveys, and also the greatest diversity of weeds, with seven documented invasive species. The next largest weed acreage was in Sub-Reach 1b, with almost 40 acres. Reach 2 had 25 acres, while Reaches 3 and 4 had surprisingly tiny amounts of invasive exotics, less than one acre total. Reach 5 had 14 acres, mostly consisting of a few large eucalyptus stands.

DISCUSSION

Restoration potential

The study is but one tool for managing the San Joaquin River. It provides reliable baseline data needed to help decide how the river is used by cities, industry, agriculture, and in the natural environment. Our transect data, the GIS layers of natural vegetation, and an understanding of adjacent land use will all contribute to the ability to make those decisions. It is hoped that these data will function dynamically and when combined with ground water, cross-sectional and other hydrologic data for the same reaches, will provide agency decision makers with the information to make effective choices.

Factors particularly important in evaluating the restoration potential of any given portion of the river include: presence/extent of exotic invasive species, proportion of native riparian species, adjacent land use, ground water, erosion, sedimentation, and the seasonal cycle of river stages (O'Neill, et.al,1997). Restoration of riparian vegetation is likely to be most successful in those portions of the river that contain high proportions of natives (as seed/propagule sources), where exotic weeds can be kept under control, and in which flows may be manipulated to provide fresh sand bars to encourage riparian tree species recruitment (Griggs and Small, 2000). In addition, if efforts supported by federal and State agencies are combined with community-based focus on areas near urban centers with aesthetic and recreation potential, the likelihood of long-term success will be considerably enhanced.

Reach 1, adjacent to the Fresno metropolitan area, offers such a scenario. The San Joaquin River Parkway has already expressed an interest in cooperative restoration projects, and preliminary design work is underway. Of particular interest is the possibility of channel and floodplain modifications proposed for the Milburn area, bordering the city limits in Fresno. Gravel extraction and various flood events have combined to produce a non-functional stretch of the river, in river mile 247, characterized by breached berms and warm-water ponds similar to the former condition of the Ratzlaf Reach on the Merced River. On that section of the Merced River, a rebuilt berm and floodplain, appear to have helped restore floodplain and channel function, and riparian vegetation is being reestablished through natural recruitment and direct plantings. Combining weed control efforts throughout Reach 1 of the San Joaquin River, a task under consideration by the Bureau, with channel and floodplain modifications would aid in restoring aesthetic and functional values to this section of the river.

In Reach 2, a pilot flow study (Jones and Stokes, 2000) investigated the effect of increased flows on the establishment of riparian tree species, particularly willows and cottonwoods. For this study, flows were increased from May through to September. Preliminary results of this study indicate differential responses of cottonwoods versus Goodding's willows (*Salix gooddingii*) to the timing of flows, and that scouring flows are critical to create bare areas for recruitment of these species. Establishment of willows and cottonwoods is episodic (approx. 10 year intervals), and gradual tapering off from peak flows could be important for survival. Continuation of this study, and others like it, in the San Joaquin basin (cf. Stillwater Sciences, 2001) will be instrumental in understanding recruitment of riparian vegetation, and establishing methods for large-scale restoration using modifications of the flow regime. Baseline data obtained from the pilot flows, as well as from the San Joaquin study described in these pages, will help gauge the effects of deliberately altering hydrology to encourage natural recruitment/establishment processes.

Reaches 4 and 5 are largely within and/or adjacent to the various units of the San Luis National Wildlife Refuge complex. These large areas of public land contain the greatest extent of floodplain vegetation in our study area. The proportion of native vegetative cover and the width between confining levees is greatest, as well. Nonetheless, miles of the San Joaquin River have significant riparian vegetation limited to one bank or the other as the river meanders in and out of the refuge units. Restoration potential would be high for those areas if acquired as part of public or private conservation efforts. The proportion of native vegetation cover is greater than upstream possibly because of the relatively high water table in these reaches as well as the adaptations of native plants to the salinity/alkalinity of the soils and river water. Thus seeds and propagules are in close proximity to potential restoration sites. Weedy species are also not as abundant, in Reaches 4 and 5, as in other areas.

RECOMMENDATIONS FOR FUTURE STUDIES/ACTIONS

As in most scientific investigations, time spent collecting data on vegetation on the San Joaquin River has led to as many questions as answers. The following is a "laundry list" of recommended studies to further the understanding of habitat and biological processes on this river system:

1) Revisit all or some subset of the transects in five years in order to document changes. Photo points should be revisited, and photos retaken. Aerials could be georectified, and overlain on the GIS data to document any habitat boundary shifts. Additional transects could be established in areas of interest, for example, where boundary shifts are notable, or where species recruitment occurs.

2) Encourage and support academic work related to questions on predominance of native herbaceous species in Reaches 4 and 5, and regarding alpha and beta species diversity (within habitat vs. between habitat diversity) which apparently declines as one travels upstream.

3) Conduct more intensive study of recruitment of riparian tree species. DBH size-class data suggests episodic recruitment in the downstream reaches. This would be worth further study, perhaps using increment borers to more accurately age specimens.

4) Analyze coarse woody debris (CWD). CWD has importance to all aspects of aquatic and terrestrial life on the rivers and wetlands of the San Joaquin river. Most studies of coarse woody debris on the North American continent have, until recently, focused on forests of the Pacific Northwest and the eastern U.S. (Lofroth, 1998, and references therein). Coarse woody debris plays an enormous role in the ecology of both terrestrial and aquatic ecosystems. With the completion of this study an opportunity exists to compile CWD data in the context of a completed, detailed investigation of the extant vegetation.

5) Document aquatic invertebrate assemblages in this river system, and usage of CWD and other substrate.

6) Assess the utility of applying DFG's Wildlife Habitat Relations system (WHR) to the San Joaquin River. Since the habitats have now been delineated more precisely than before, the next step is to refine the WHR system to more accurately reflect the habitat usage in the San Joaquin drainage.

7) Document avian usage and nesting throughout the riparian habitat.

8) Digitize the 1914-1917 ACOE maps of the San Joaquin River, originally made for the California Debris Commission, to compare the river's morphology of 1914-17 with the current situation. Anecdotal comparisons during the 2000 field season showed that some of the historical sandbars are in apparently the same placement and configuration in the modern channel as they were in the early part of the century. This is curious, considering that construction of Friant, and other dams, as well as canals and levees, have since altered the hydrologic regime.

9) Initiate eradication measures on exotic invasives, such as *Arundo*, tree of heaven *Eucalyptus*, etc. Follow up with annual surveys to determine effectiveness of eradication techniques, identify new infestations, etc.

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